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RESPOND POST FAULT ANALYSIS

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1 INTRODUCTION

The Electricity North West's Respond, second tier Low Carbon Network funded project, is investigating active fault level management techniques as a cost beneficial alternative to traditional reinforcement of network assets.

Three fault level mitigation techniques are being trialled as part of the Respond project. Performance of these techniques is assessed by examining the systems' behaviour in response to a fault. This report presents the analysis of a fault event occurring during the Respond trial in accordance with Successful Delivery Review Criteria, SDRC 9.3.3, as shown below.

CRITERIA	EVIDENCE
3. Implement monitoring and post fault analysis procedures in Trial period	3. Publish on Respond website a summary of each fault event three months after each event, with the expectation that a minimum of 18 faults will be reported on

2 EVENT DETAILS

Substation	Atherton Town Centre
Fault Mitigation Technique	Adaptive Protection
Voltage	11kV
Date/Time	16 September 2016 / 28.25.24
Faulted Circuit	York St. Sw. Stn. 11kV circuit
Fault Location	The fault was located outside No. 70 Car Bank St. near the Tee off to Devonshire Rd substation on the section of the 11kV circuit between First Ave and Derby St substations.

3 SITE AND INSTALLATION INFORMATION

3.1 NETWORK DATA

The pre-fault Atherton Town Centre network configuration is shown in Figure 3-1. For the Respond trials, the 11kV transformer incomer CTs are connected in parallel. The respective phase current input to the Adaptive Protection high-set instantaneous overcurrent relay (50) receives the sum of the current in each transformer incomer. Operation of the Adaptive Protection initiates the tripping of the11 kV bus section circuit breaker, increasing the impedance to the fault and reducing the initial fault current.

Pre-fault loading information is shown in Table 3-1.

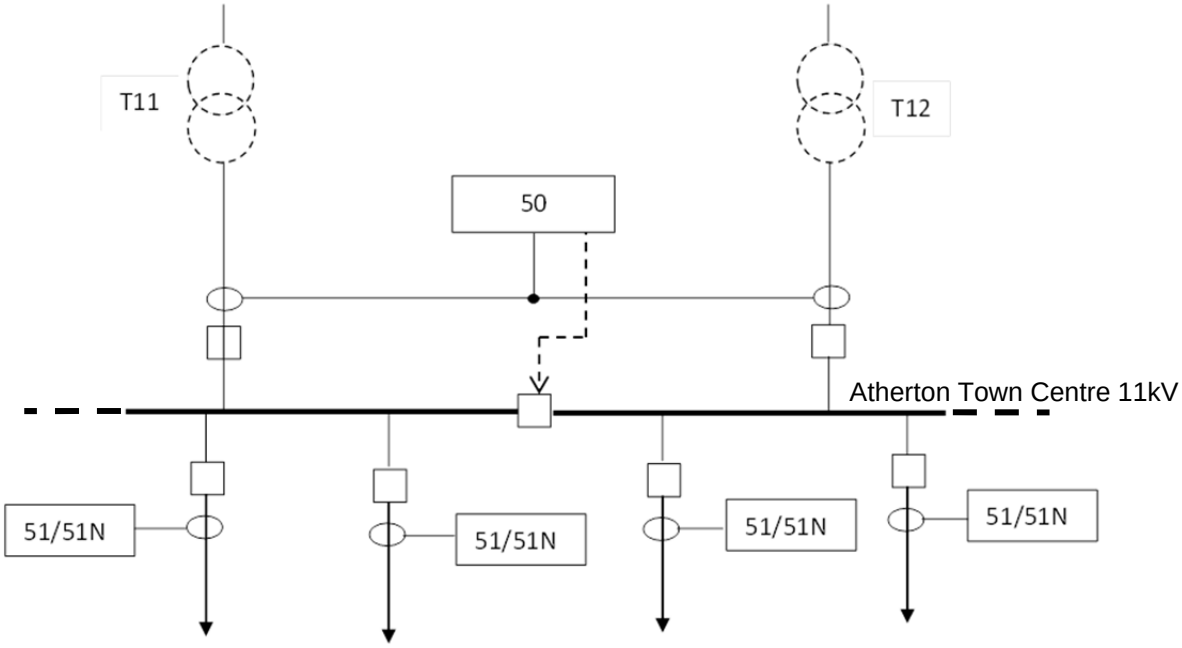

Figure 3-1: Atherton Town Centre Network

Table 3-1: Pre-fault Load Conditions

Pre-fault load data (1/2hour)	
Atherton Town Centre	719.85 A
York St. Sw. Stn. Feeder	51.64 A

3.2 PROTECTION DATA

The Adaptive Protection has the facility to be remotely switched in and out of service, however in this case it is permanently enabled.

Table 3-2: Atherton Town Centre Adaptive Protection Settings

CT	4000/5
Relay	MiCOM P40 Agile P145
I>1 Function	Disabled
I>2 Function	Disabled
I>3 Status	Enabled
I>3 Direction	Non-Directional
I>3 Current Set	4520A
I>3 Time Delay	0 s (The manufacturer's declared accuracy for definite time (DT) operation is ±2% or 50ms, whichever is greater.)
I>4 Status	Disabled
Comment	The setting of 4520 A is well below the short circuit capability of the Atherton Town Centre 11 kV switchgear (25 kA), but this value is selected for these trials to ensure operation for 11 kV phase faults.

Table 3-3: York St. Sw. Stn. 11kV Feeder Protection Settings

CT	400/5
Relay	MCGG52 (2 Phase Overcurrent and Earth Fault)
I>	I.7 x In (680 A)
t>	0.4, Standard Inverse
Io>	0.3 x In (120 A)
to>	0.4, Standard Inverse

3.3 EVENT INFORMATION

3.3.1 Fault Level Calculations

The calculated values of fault current from the Fault Level Assessment Tool (FLAT) and Dinis are as shown in Table 3-4.

Table 3-4: Fault Current Values

Schneider NMS FLAT Fault Current Values (for substations near the fault location)	
Three Phase Fault Level at:	
Atherton Town Centre Primary	7.86 kA
L-L-G Fault Level at:	
Derby St (216372)	5.681 kA
First Ave (216490)	6.337 kA
Near Fault Location	5.861 kA
Dinis Fault Current Values for fault location	
DINIS fault calculation (Only for L-L and L-L-G faults):	Red = 0 kA /0° Yellow = 6.842 kA /195° Blue = 5.822 kA /26° Residual = Not listed

3.3.2 Recorded Fault Current

The fault currents recorded by the relay in the red and yellow phases (7756 A and 6277 A respectively), as shown in Table 3-5, although greater than the DINIS phase to phase to earth fault current results, do show some correlation, particularly considering that the modelling of the upstream system in Dinis is based on an assumption. However, it is noted that the FLAT phase to phase to earth fault current results are the same for the two phases, and the difference between

the measured values is even larger than for the DINIS results, probably indicating an omission or error in the zero sequence parameters within the FLAT network representation.

Table 3-5: Comparison with Recorded Currents

Phase	Adaptive Protection Relay Recording	Schneider NMS FLAT-Calculated L-L-G Fault Level (at Manchester Rd S/S)	DINIS Calculated L-L-G Fault Level (at Jose Holt Gordon)
Red	7756 A	5861 A	6842 A (195°)*
Yellow	6277 A	5861 A	5288 A (26°)*
Blue	800.1 A	-	0 (0°)*
Residual	909 A	-	-

* DINIS Phase fault currents are interposed to match the actual red–yellow phase to earth fault.

4 EVENT TIME LINE

4.1 EVENT TIMES FROM CRMS

The event recorded at the CRMS are shown in Table 4-1

Table 4-1: Event Timings

Time	Event
18:25:24	Atherton Town Centre 11 kV Feeder Earth Fault and Neutral Current Alarms
18:25:26	Atherton Town Centre- York St. Sw. Stn. 11 kV Feeder CB opened
18:26:20	Atherton Town Centre- York St. Sw. Stn. 11 kV Feeder CB auto-closed
18:26:43	Atherton Town Centre 11 kV Neutral Current Alarm
18:26:44	Bus Section Adaptive Protection (AP) Stage 1 operated
18:26:44	Atherton Town Centre A-B Bus section CB opened
18:26:45	Atherton Town Centre- York St. Sw. Stn. 11 kV Feeder CB opened
18:27:16	Atherton Town Centre- York St. Sw. Stn. 11 kV Feeder CB auto-closed

4.2 DISTURBANCE RECORDS

The instantaneous and RMS disturbance records obtained from the Adaptive Protection relay are shown in Figure 4-1 and Figure 4-2 respectively.

In these figures, Output R3 is the trip signal from the Adaptive Protection to the 11 kV bus section circuit breaker and output R12 is the bus section circuit breaker “a” auxiliary contact repeat signal to telecontrol.

The trigger for the disturbance recorder is the operation of the Bus Section Adaptive Protection Stage 1. The total recording time of the MiCOM P40 Agile P145 Adaptive Protection relay is set for 1.5 secs, with a pre-trigger recording time of 0.5 secs and a post trigger recording time of 1.0 secs.

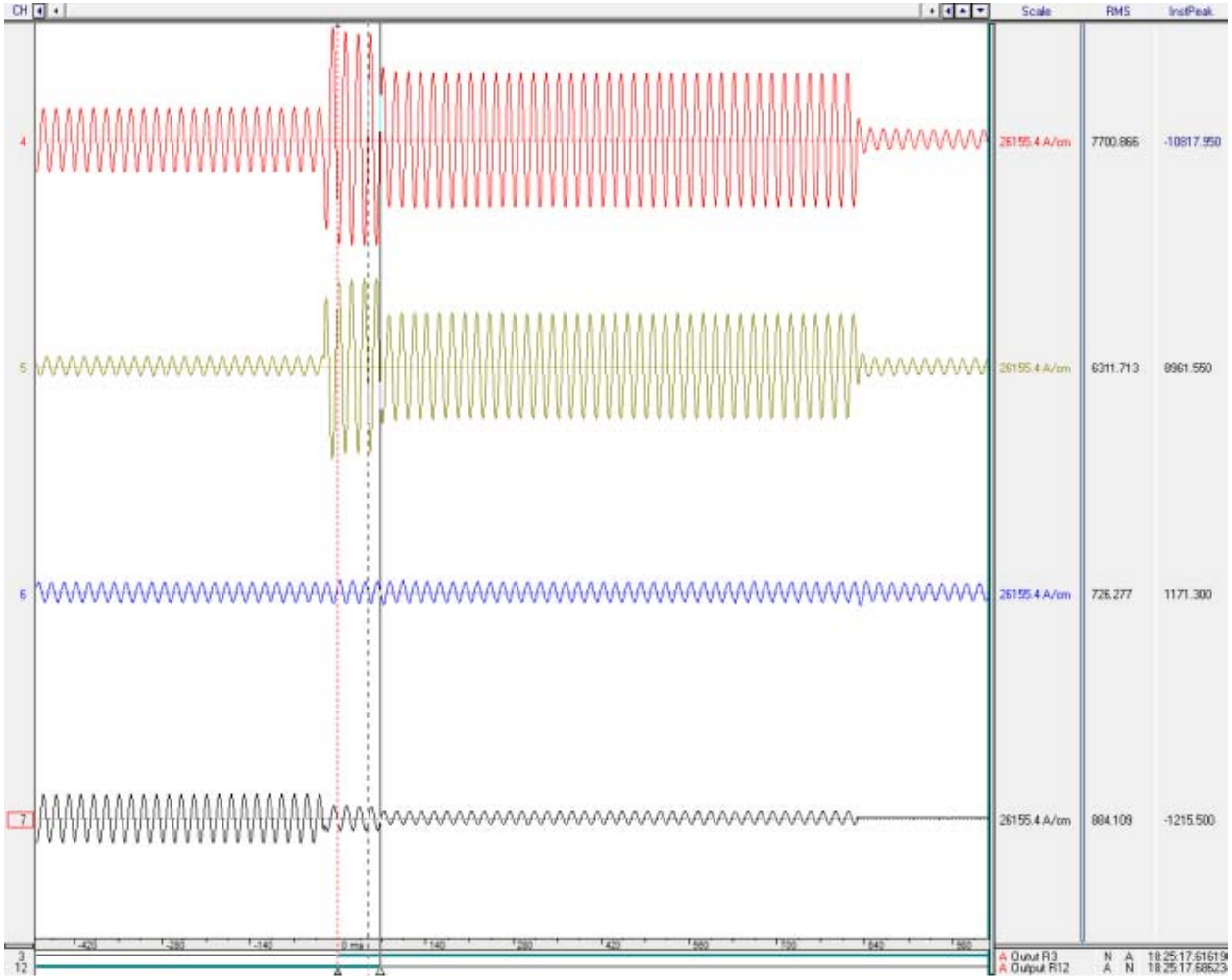

Figure 4-1: Instantaneous Adaptive Protection Relay Recordings (IA=red, IB=yellow, IC=blue and IN(residual)=black)

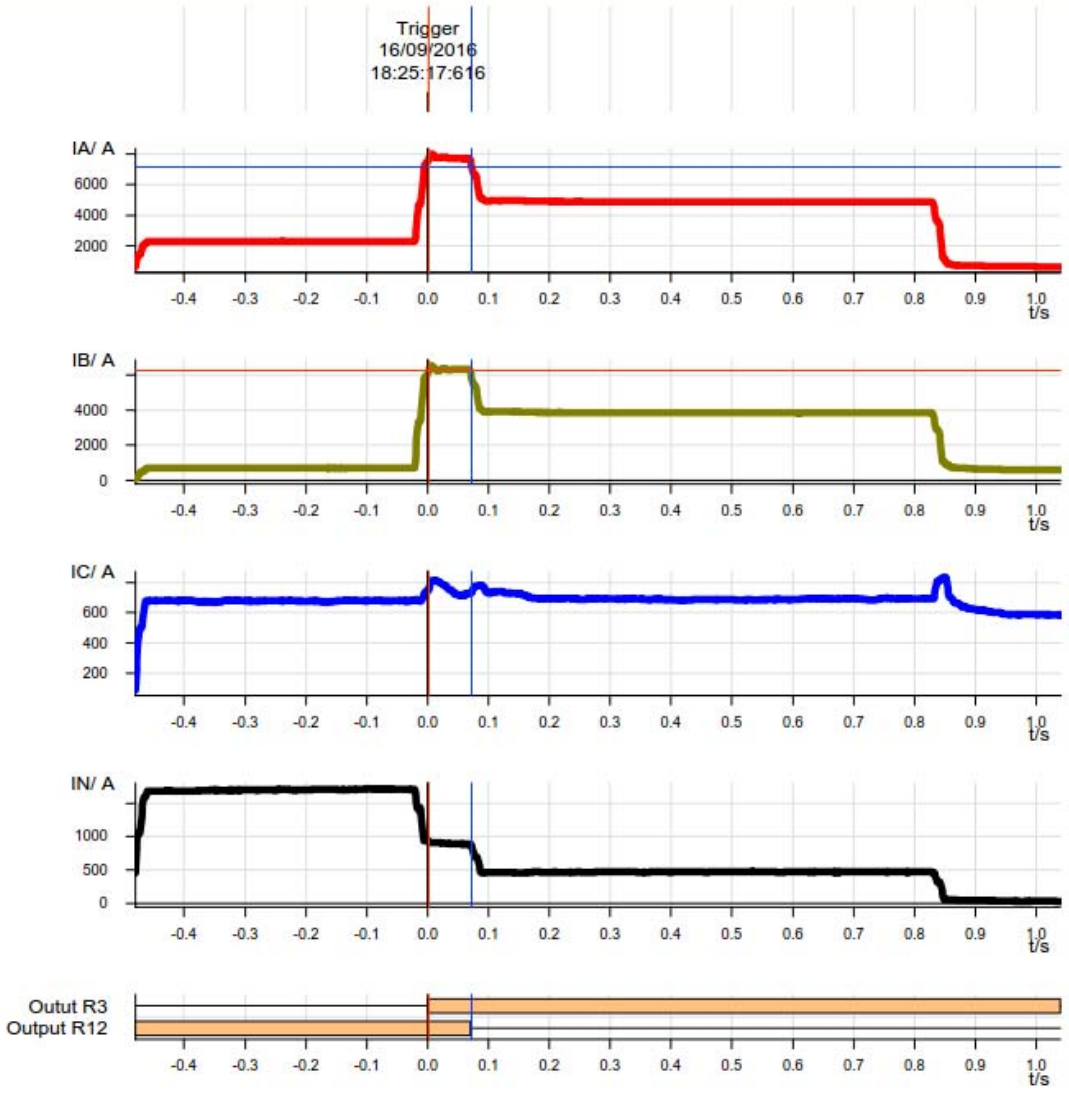

Figure 4-2: RMS Adaptive Protection Relay Recordings

5 DISTURBANCE ANALYSIS

As recorded on the CRMS log, this incident started as a phase earth fault on the York Street Switching Station 11 kV feeder. This initial fault was detected by the 11 kV feeder earth fault protection which initiated the tripping of the feeder circuit breaker. The feeder circuit breaker then auto- closed. Based on the 11 kV Neutral Current alarm indicated on the CRMS log, it is clear that the initial phase to earth fault was still present when the circuit breaker re-closed.

The Adaptive protection pick-up current setting is above the earth fault current magnitude which is limited by the earthing resistors at Atherton Town Centre substation. The initial phase to earth fault, tripping and re-closing of the York Street Switching Station 11 kV feeder circuit breaker is therefore not captured on the disturbance records.

The disturbance records do however show that after the York Street Switching Station 11 kV feeder circuit breaker auto-closed, that there was a red phase to earth fault present prior to the phase to phase to earth fault which the Adaptive Protection responded to. The magnitude of the earth fault current was 1712.7 A with a corresponding red phase fault current of 2306.7 A (inclusive of load current).

The phase to phase to earth fault with 7652.5 A and 6262.7 A in the red and yellow phases respectively and with a 918.7 A residual fault current, occurred 22.5 ms prior to being detected by the Adaptive Protection relay. The 11 kV bus section circuit breaker tripped 70.9 ms after the trip signal from the Adaptive Protection relay was sent. The total duration of the phase to phase to earth fault which the Adaptive Protection responded to, up to the tripping of the 11 kV bus section circuit breaker was 93.4 ms.

After the 11 kV bus section circuit breaker tripped, the phase to phase to earth fault current reduced to 4979.4 A and 3923.2 A in the red and yellow phases respectively and the residual fault current reduced to 463.4 A. These fault currents continued for a further 758.9 ms, until the feeder protection operated i.e. the fault was eventually cleared 829.8 ms after the Adaptive Protection detected the initial phase to phase to earth fault.

The residual current is seen to reduce from 918.7 A to 463.4 A (a reduction of approximately 50%). This reduction in residual current reflects the dominant effect of the earthing resistors at Atherton Town Centre substation and the expected doubling of the earth resistance as the bus section is opened and the earthing resistors on each bus section are no longer in parallel.

Table 5-1 summarises the fault current durations. Table 5-2 summarises currents obtained from the disturbance records, Pre-AP Operation and Post-AP Operation currents are relative to the fault current which triggered the Adaptive Protection (AP Fault Currents). Post Fault Current is the current after operation of the feeder protection.

Table 5-1: Fault Current Durations

Phase Fault Inception	Adaptive Protection Operated	11 kV Bus Section Tripped	11 kV Feeder Protection Operated
0 ms	22.5 ms	93.4 ms	852.3 ms

Table 5-2: Disturbance Recorder Currents

	Pre-AP Operation Current	AP Fault Current	Post-AP Operation Current	Post-Fault Current
Red	2306.7 A	7652.5 A	4979.4 A	648.1A
Yellow	684.3 A	6262.7 A	3923.2 A	598.8 A
Blue	677.9 A	753.7 A	731.3 A	586.5 A
Residual	1712.7 A	918.7 A	463.4 A	32.12 A

6 CONCLUSIONS

The fault as recorded on the disturbance recorder integral to the Adaptive Protection relay confirms the events observed from the CRMS following initial reclose of the York Street Switching Station 11 kV feeder circuit breaker. The initial operation of the Neutral Current alarm corresponds to the earth fault current seen in the disturbance records prior to the Adaptive Protection operation. The Adaptive protection pick-up current setting is above the earth fault current magnitude which is limited by the earthing resistors at Atherton Town Centre substation. The disturbance recorder therefore did not trigger for the phase to earth

fault but it was captured in pre- fault recoding when it triggered for the phase to phase to earth fault.

The reduction in the fault currents due to the opening of the 11 kV bus section circuit breaker is clearly seen. The reduction in the phase fault currents in this case is as expected, although no generalisations can be made as the degree of the reduction will depend on the relative magnitudes for the source impedance, circuit and transformer impedances and fault resistance.

The residual current is seen to reduce from 918.7 A to 463.4 A (a reduction of approximately 50%). This reduction in residual current reflects the dominant effect of the earthing resistors at Atherton Town Centre substation and the expected doubling of the earth resistance as the bus section is opened and the earthing resistors on each bus section are no longer in parallel.

The phase to phase to earth fault was present for 22.5 ms before the Adaptive Protection was triggered. In this case the fault current was only a multiple of 1.69 times the Adaptive Protection I>3 current setting. For fault currents greater than a multiple of 2 times the current settings, the detection time should decrease.

The time between the Adaptive Protection issuing the trip signal and the 11 kV bus section circuit breaker tripping is largely dependent on the circuit breaker operating time and would not change with fault current.

Overall, the analysis has confirmed that the Adaptive Protection operated as expected and reduced the fault current to be interrupted by the feeder circuit breaker.